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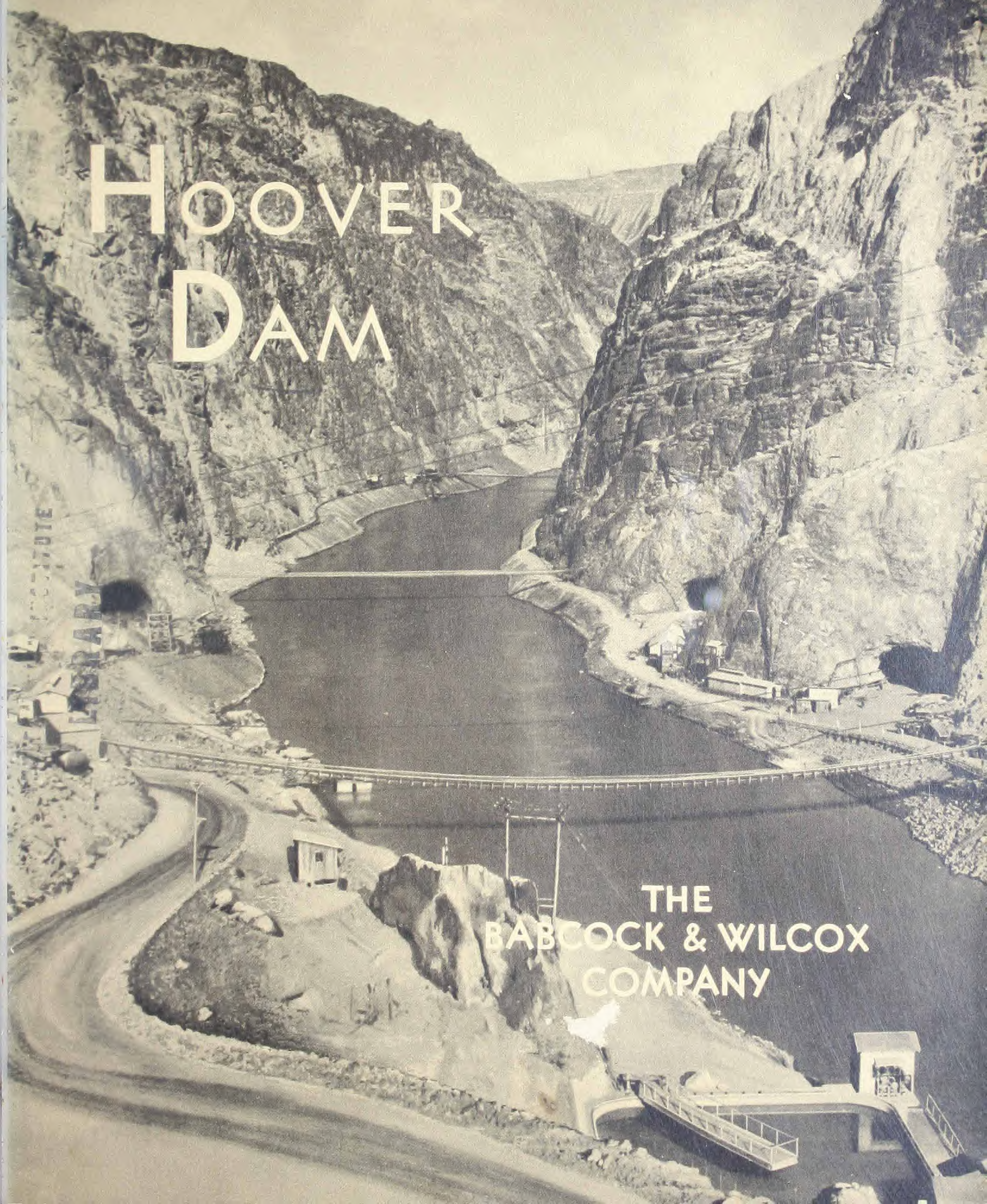
HOOVER DAM



THE BABCOCK & WILCOX COMPANY

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H. J. Harris

HOOVER DAM

Bulletin S-4

ACKNOWLEDGMENT

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THE BABCOCK & WILCOX COMPANY

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FOREWORD

THE Boulder Canyon project, including Hoover Dam, designed to tame the annual wild rush of the waters of the Colorado River, to provide ultimately for the irrigation of about 2,000,000 acres of arid but otherwise fertile land, and to generate enough power to make the project self-liquidating, is an undertaking that will mark an epoch in the history of the great engineering achievements of the world.

The Babcock & Wilcox Company is proud of the substantial part it is privileged to take in this stupendous undertaking, and presents in the following pages a brief description of the project as a whole, and the more noteworthy features of the fabrication and installation of the fusion-welded plate-steel pipes—the largest the world has ever seen—to be furnished by the Company for the hydraulic-power and normal-flow-control tunnels of Hoover Dam.

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Looking upstream in Black Canyon directly above the site of Hoover Dam.

The location of Hoover Dam with reference to surrounding territory is shown by this map. Note the irrigable areas in the lowlands near the mouth of the Colorado River. Imperial Valley varies in elevation from sea level at its southern extremity to 250 feet below sea level, at Salton Sea. Properly irrigated, it is a land of abundant fertility . . . periodically faced with disaster from floods, should the Colorado River overflow its banks, situated about 100 feet above the high level of the Valley.

The Colorado River

THE waters of the Colorado River originate almost exclusively from the melting snows on the Pacific slope of the Rocky Mountains. Cloudbursts in the summer and heavy rains throughout the river's drainage area make the flow exceedingly erratic, swelling to torrential proportions in the spring. Whereas the minimum flow at Black Canyon is only about 5000 cubic feet per second, the measured maximum flow has reached 210,000 cubic feet per second, and unmeasured floods have reached flows believed to be as high as 300,000 cubic feet per second. Damage costing millions of dollars has been wrought by the Colorado, and millions have been spent to protect Imperial Valley alone from being inundated; but the fury of the Colorado in the flood season presents, in spite of man's best efforts to date, a danger of the gravest sort to the country along its banks and the lowlands around the delta of the river.

The destructive force of these floods is increased enormously by the drop of more than 9000 feet from the head waters in Wyoming and Colorado to the delta at the Gulf of California. This great difference in elevation produces velocities of flow exceeding 10 miles per hour in some parts of the river, with the result that huge quantities of silt are carried down stream by the erosive, turbulent currents. This silt, which is sometimes as much as 15 per cent of the volume of the flow, is washed into the irrigation channels in the agricultural regions adjoining the lower part of the river, and must be dredged out, or the channel banks must be raised, to prevent the water from overflowing the banks as the silt is deposited on the channel beds.

Boulder Canyon Project

FOR more than fourteen years, the Bureau of Reclamation of the United States Department of the Interior worked on the perfection of a plan whereby the periodic ravages of this temperamental river might be eliminated and its power diverted to useful and profitable ends. Finally, the Bureau developed a plan that is now being carried out under the direction of Dr. Elwood Mead, Commissioner of the Bureau. The plan includes:

1 The construction of a dam, in one of the canyons of the Colorado River, large enough to control the flow of water at all times, to provide flood storage, to store water for irrigation and domestic use, and to serve as a settling basin for mud and silt.

2 The excavation of the All-American Canal, to conduct, for irrigation purposes, water from the Colorado at a point above Yuma, Arizona, to the farm lands in south-eastern California.

3 The construction of a power plant, immediately below the dam, to generate electrical energy, the sale of which would make the entire project self-liquidating.

This plan became known as the Boulder Canyon Project and, as such, was passed by act of Congress and, on December 21, 1928, approved by President Coolidge. As a matter of fact, the final choice of the site for the dam was not at Boulder Canyon but at Black Canyon, about 20 miles down stream; and on September 17, 1930, at a ceremony held to celebrate the beginning of the work, Secretary Wilbur, of The Department of The Interior, named the proposed structure Hoover Dam, in recognition of President Hoover's efforts in behalf of the project.

The authorized cost of the project is:

Hoover Dam and reservoir....	$ 70,600,000
Power development equipment	38,200,000
All-American Canal........	38,500,000
Interest during construction period..................	17,700,000
Total.............	$165,000,000

Courtesy The Union Pacific System
(Los Angeles & Salt Lake Railroad Company)

Topographical map of Hoover Dam and adjacent country. Black Canyon was selected as the site for the dam, as it lends itself more readily to a construction of this nature than does Boulder Canyon. Black Canyon is more accessible, its walls are steeper, and a dam to provide the same storage capacity would accordingly cost less. In addition, the rock at this point is better suited to the purpose, being easier to drill and having fewer open fractures.

Hoover Dam and Reservoir

WHEN completed, Hoover Dam will be the highest and largest ever constructed. It is to be of the arch-gravity type, 45 feet thick at the top, 650 feet thick at the base, and will rise about 730 feet above the foundation rock. Its length along the top will be 1180 feet.

The dam proper will contain about 3,400,000 cubic yards of concrete masonry, and 1,000,000 cubic yards more will be used in constructing the power house and related structures. The total quantity of concrete, 4,400,000 cubic yards, would be sufficient to build 2255 miles of highway, 20 feet wide and 6 inches thick.

The engineering and construction problems that must be solved in building a dam of this size are of a magnitude and complexity that are difficult to realize. For instance, it is estimated that, because of the great mass of the dam, the heat generated by the chemical reaction accompanying the setting of the concrete would not be dissipated for over 100 years under natural conditions. In order to remove this heat quickly, and permit grouting of the construction joints in the dam at low temperature, artificial cooling will be employed by forcing cold water through a system of pipes embedded in the concrete. This system will require about 800,000 feet, or about 150 miles, of 2-inch pipe. When the cooling process has been completed, this piping

will be filled with grout under pressure and thus become a solid part of the structure.

The reservoir created will be the largest artificial lake in the world, measuring 115 miles in length and ranging from a few hundred feet at the dam to 8 miles in width. When filled, it will contain over 30,000,000 acre-feet, or about 11,000,000,000,000 (eleven trillion) gallons, of water, enough to cover the state of Connecticut to a depth of ten feet.

Under normal flow conditions it will require over two years to fill the reservoir.

The immense storage capacity of the reservoir will make possible an impressive reduction in the volume of water released during flood periods. The flood of 1884, which, it has been estimated, reached a flow at Yuma, Arizona, of 300,000 cubic feet per second, would, with control at Hoover Dam, be reduced to an outflow of but 75,000 cubic feet per second.

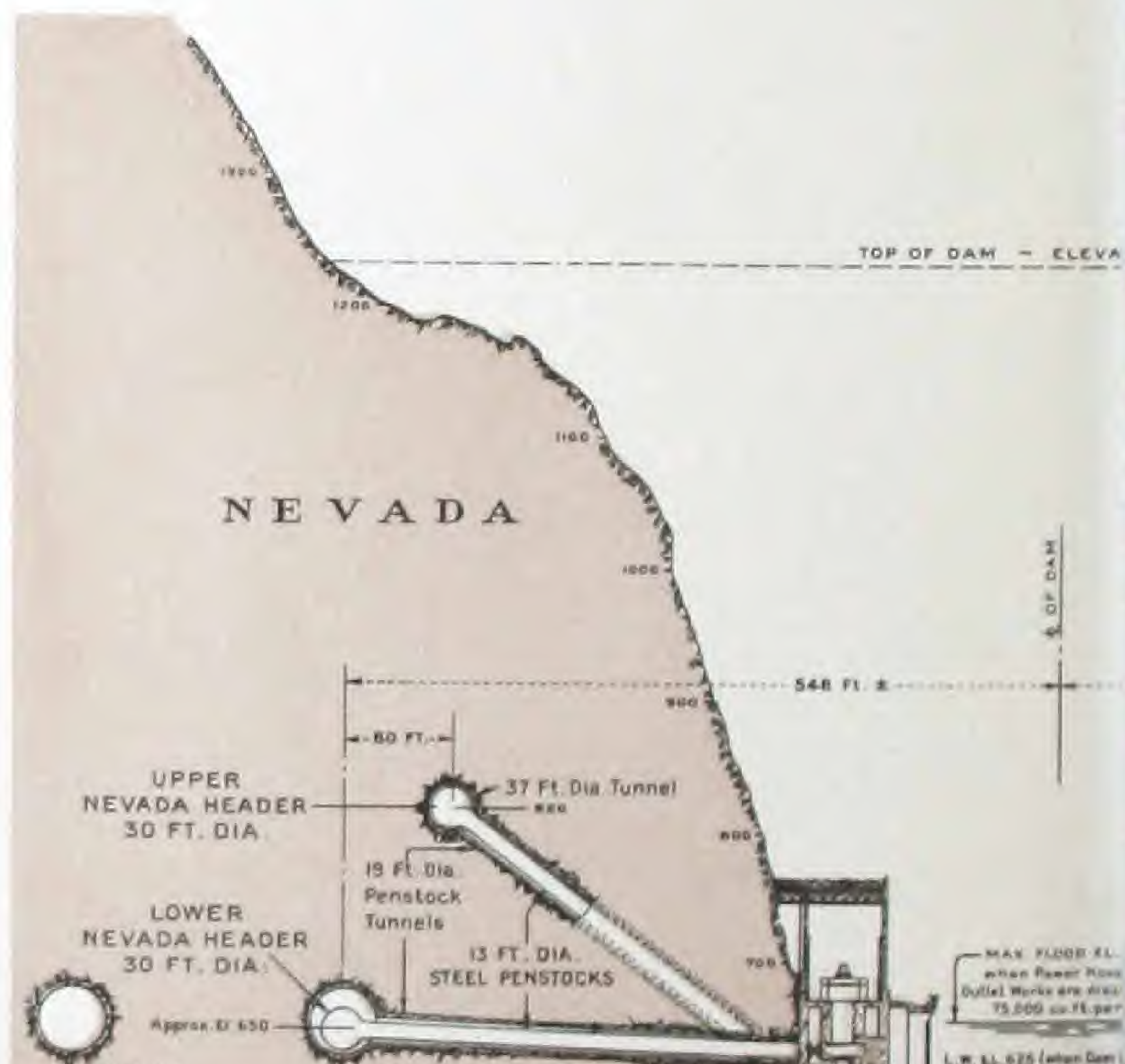
The rugged character of Black Canyon is graphically portrayed in this photograph. The rock, of volcanic origin, geologically termed "Andesite Breccia," is hard and resists change and decay from the action of the elements. The absence of top soil accounts for the barren condition of the landscape.

Diversion Tunnels

WHILE the dam is under construction, the river is being diverted through four 50-foot diameter, concrete-lined tunnels driven through the canyon walls, two on each side of the river. These four tunnels will have a total length of about 16,300 feet, or more than 3 miles.

When their use for diversion is no longer necessary, the two outer tunnels will be used for the discharge from two spillways, and the inner tunnels will accommodate steel pipes leading to the power house and tunnel plug outlet works. Two additional power tunnels, 37 feet in diameter, one on each side of the river, will also be driven through the rock, as shown below.

Schematic diagram showing a cross-section of the canyon at the power house.



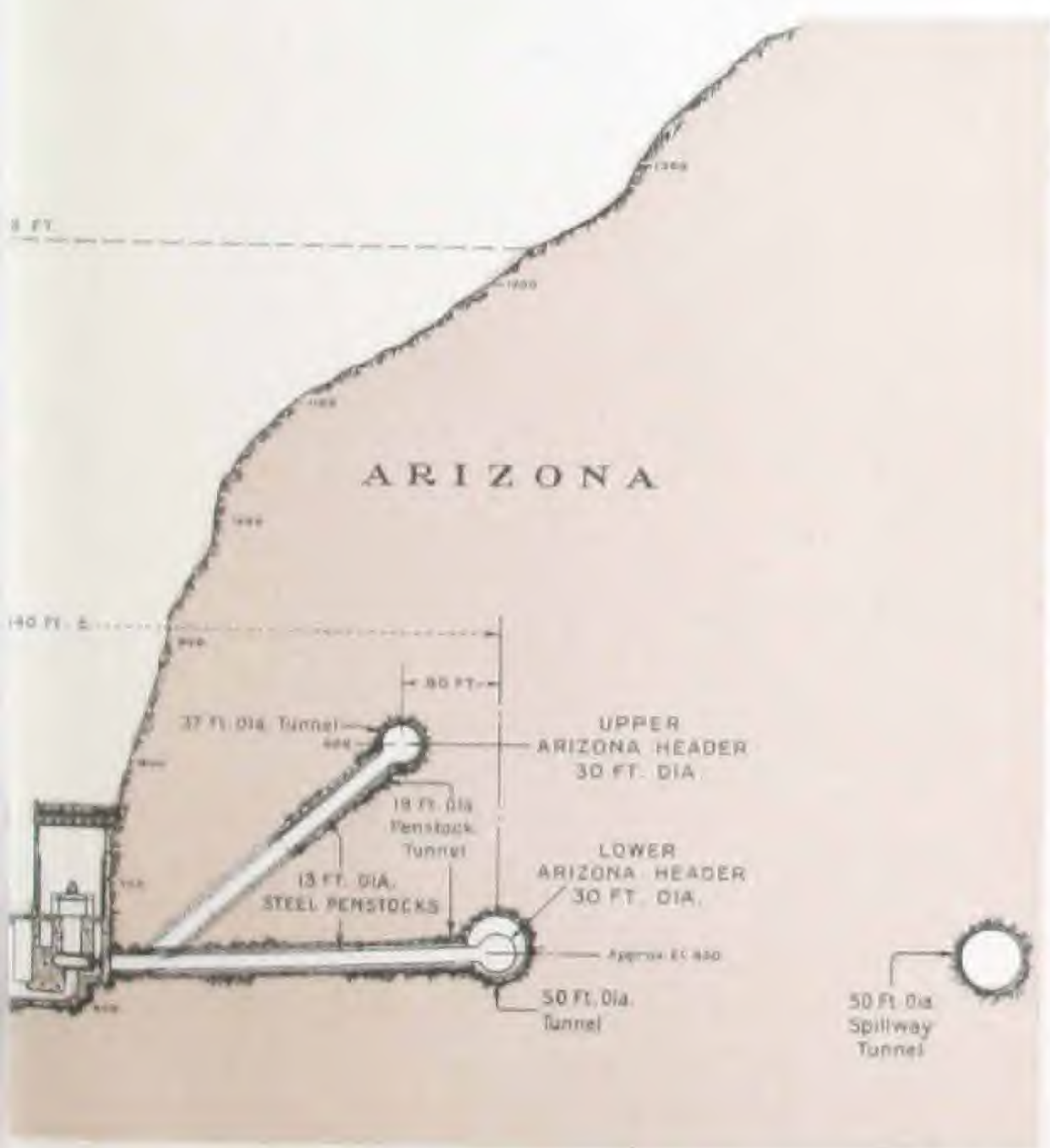
Sketch of Hoover Dam showing general arrangement of the tunnels and power house. The river bed will be excavated to a depth of 140 feet, to provide a bed-rock foundation for the dam, which will raise the surface of the river 582 feet.

Power Plant

THE power plant will be capable of developing 1,835,000 horsepower. For purposes of comparison, it might be stated that the Niagara plant (United States) has a capacity of 557,500 horsepower; Conowingo, 378,000 (ultimate 594,000) horsepower, and Muscle Shoals, 250,000 (ultimate 600,000) horsepower. The continuous firm output of the Hoover Dam power plant will be in excess of 663,000 horsepower.

The hydraulic turbines will operate under an average head of 520 feet. The minimum and maximum heads will be 420 and 590 feet, respectively.

The sale of electrical energy will, on the basis of present contracts, pay all operating and maintenance costs, interest charges, and will amortize the investment in 50 years.



Looking upstream from the cliffs on the Nevada side of Black Canyon. The dam will be located just beyond the footbridge in the foreground of the picture. Sections of pipe weighing about 150 tons must be lowered into this canyon.

Layout of the pipes to be fabricated and installed by The Babcock & Wilcox Company.

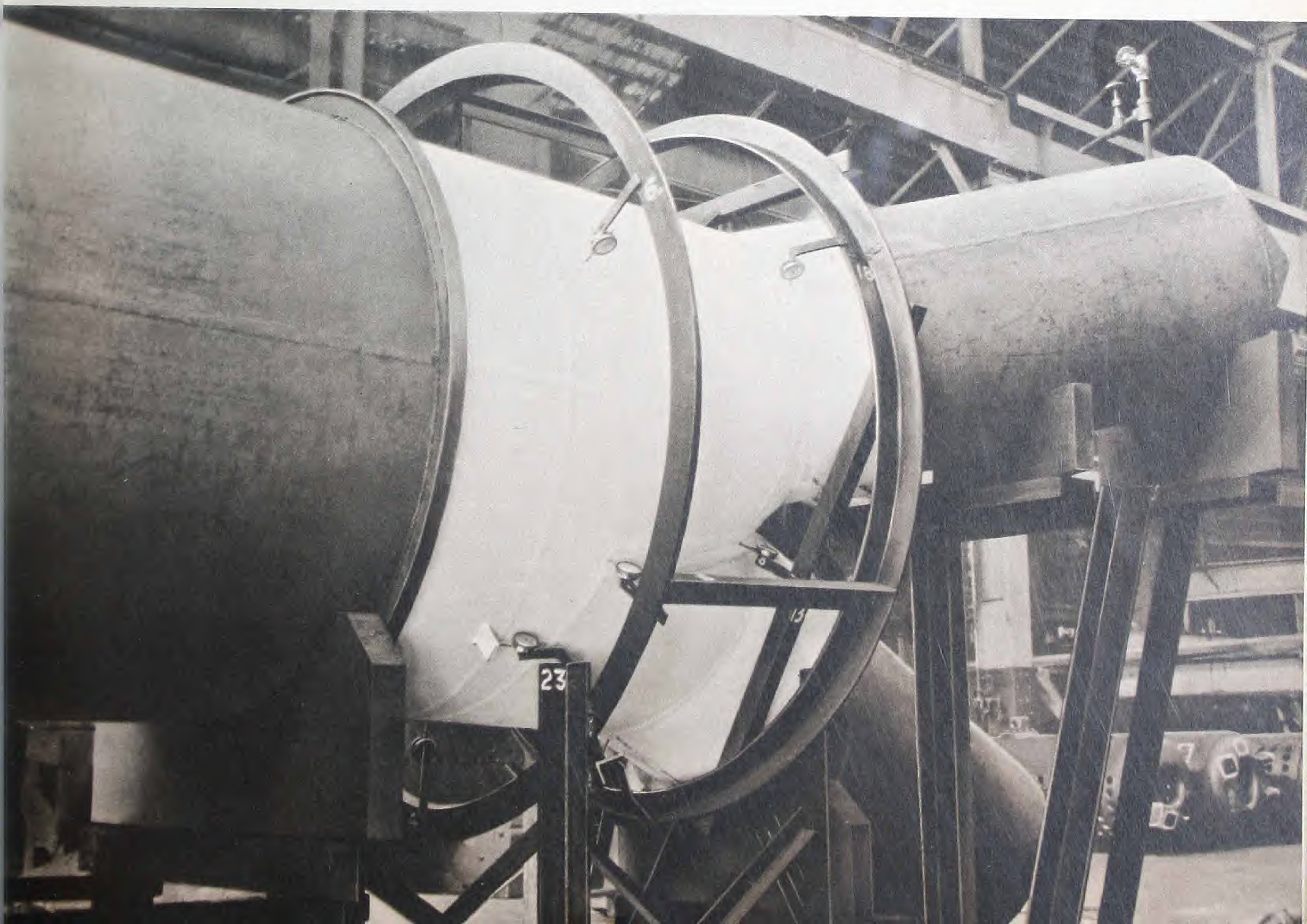
Steel Pipes

THE contract awarded The Babcock & Wilcox Company includes the fabrication and installation of fusion-welded plate-steel pipes in the hydraulic-power and outlet-works tunnels. This is the second largest contract ever let by the United States Department of the Interior, and involves such features as the construction of pipes larger than any heretofore made, the transportation and handling of pipe sections as heavy as many types of standard-gage railroad locomotives, and the exploration of welded seams by X-ray equipment of a capacity and power made available only within the past year.

Four main conduits will lead water from intake towers above the dam to the power-house and outlet-works regulating valves below the dam. There will be one upper and one lower conduit on each side of the river. The lower conduits will be located in the 50-foot diversion tunnels nearest the river and at an elevation just above the normal low-water level of the river below the dam. The upper conduits will be installed in 37-foot diameter tunnels running parallel to, and 170 feet above, the lower tunnels.

From each of the main conduits, which are 30 feet in diameter, there will be four 13-foot diameter branches leading to 17 hydraulic turbines in the power house. Below the penstock branches, the main conduits will be reduced to 25 feet in diameter, and from each of these there will be six $8\frac{1}{2}$-foot diameter branches leading to control valves located down stream from the power house. These

Test model, one-sixth the full size of one of the 30-foot diameter pipe sections, with micrometer gages arranged to show the deflection of the pipe walls under pressure.



valves will be used to regulate the flow, to the river below the dam, of surplus water not needed for the power turbines.

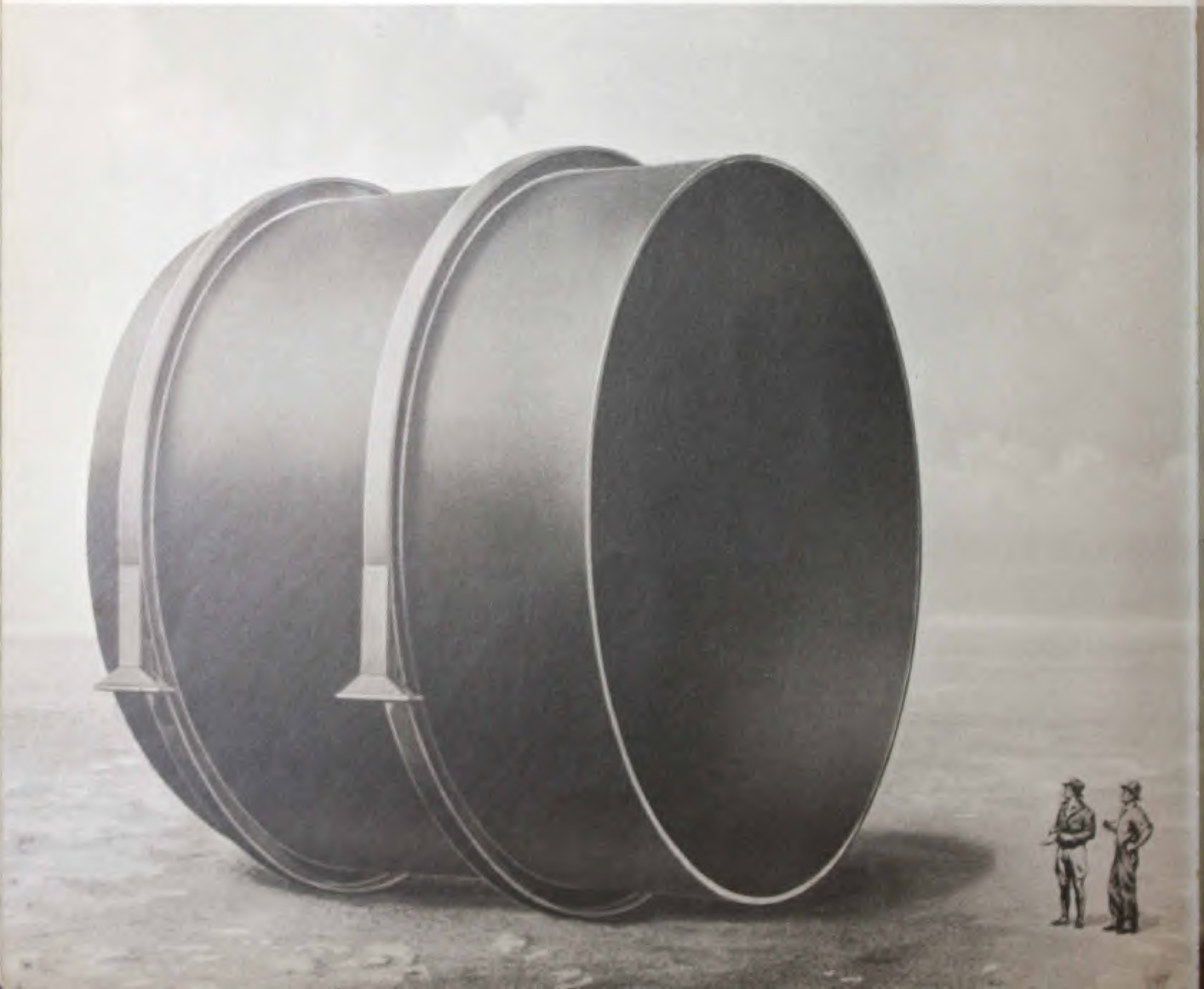
The approximate sizes of the various pipes to be fabricated are:

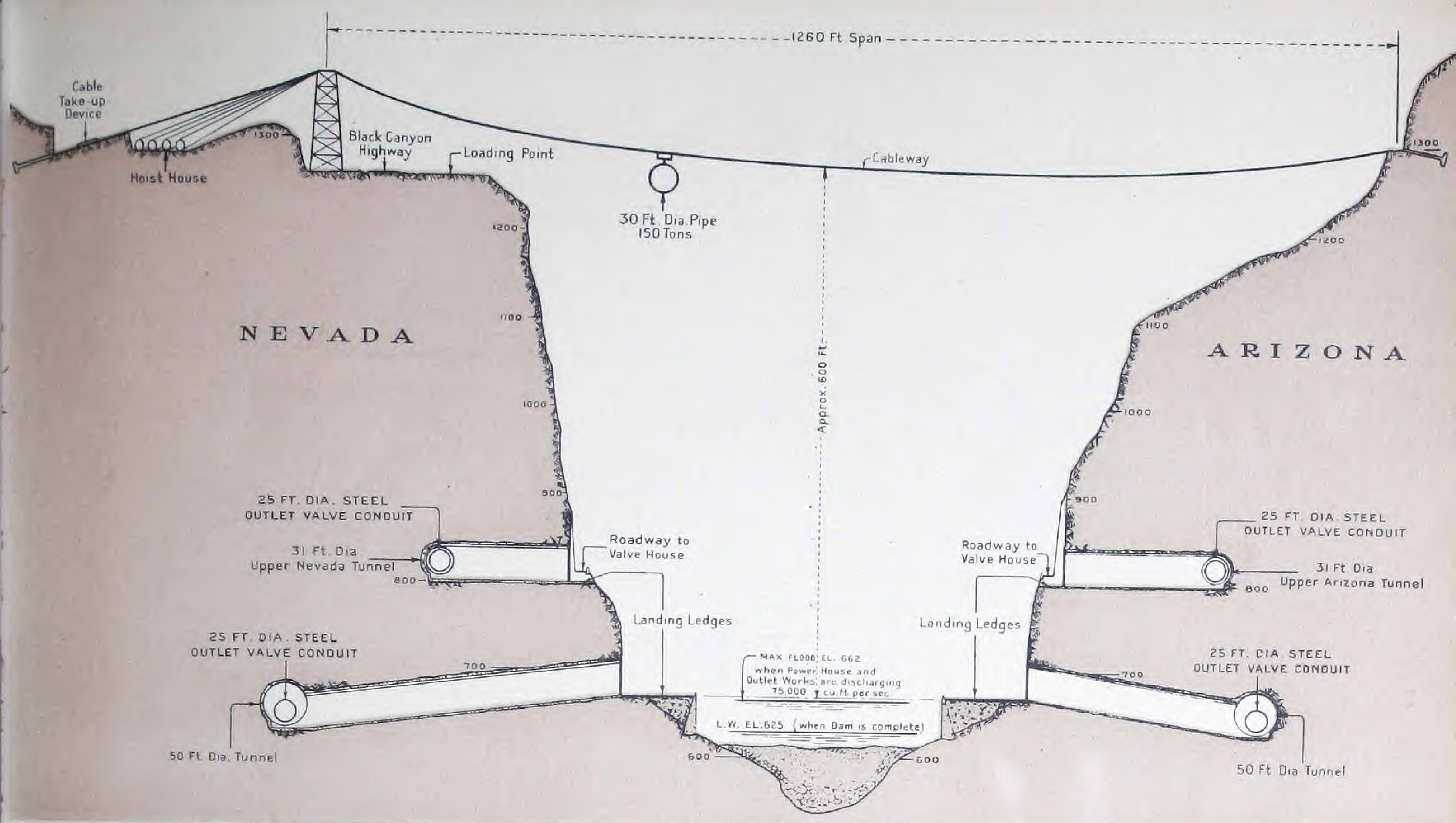
Length, ft.	Diameter, ft.	Plate Thickness, in.
4700	30	$1\frac{3}{4}$ to $2\frac{3}{4}$
1900	25	$1\frac{13}{16}$ to $2\frac{3}{8}$
5600	13	1 to $1\frac{5}{16}$
2300	$8\frac{1}{2}$	$\frac{7}{8}$ to 1

More than 50,000 tons of steel plate will be used in fabricating this 14,500 feet of pipe.

As the diameters of most of this piping are too great to permit shipment by railroads, it will be necessary to build a fabricating plant on the rocky slopes above the Canyon, about one mile from the site of the dam. The plant equipment will include, among other machinery, a plate-bending roll which, for its width, will be heavier and more powerful than any made to date, a stress-relieving furnace of sufficient size to accommodate the 30-foot diameter pipe sections, and a complete laboratory for testing weld specimens.

The comparative size of a man and a section of the 30-foot diameter pipe to be manufactured by The Babcock & Wilcox Company is strikingly illustrated in this drawing.





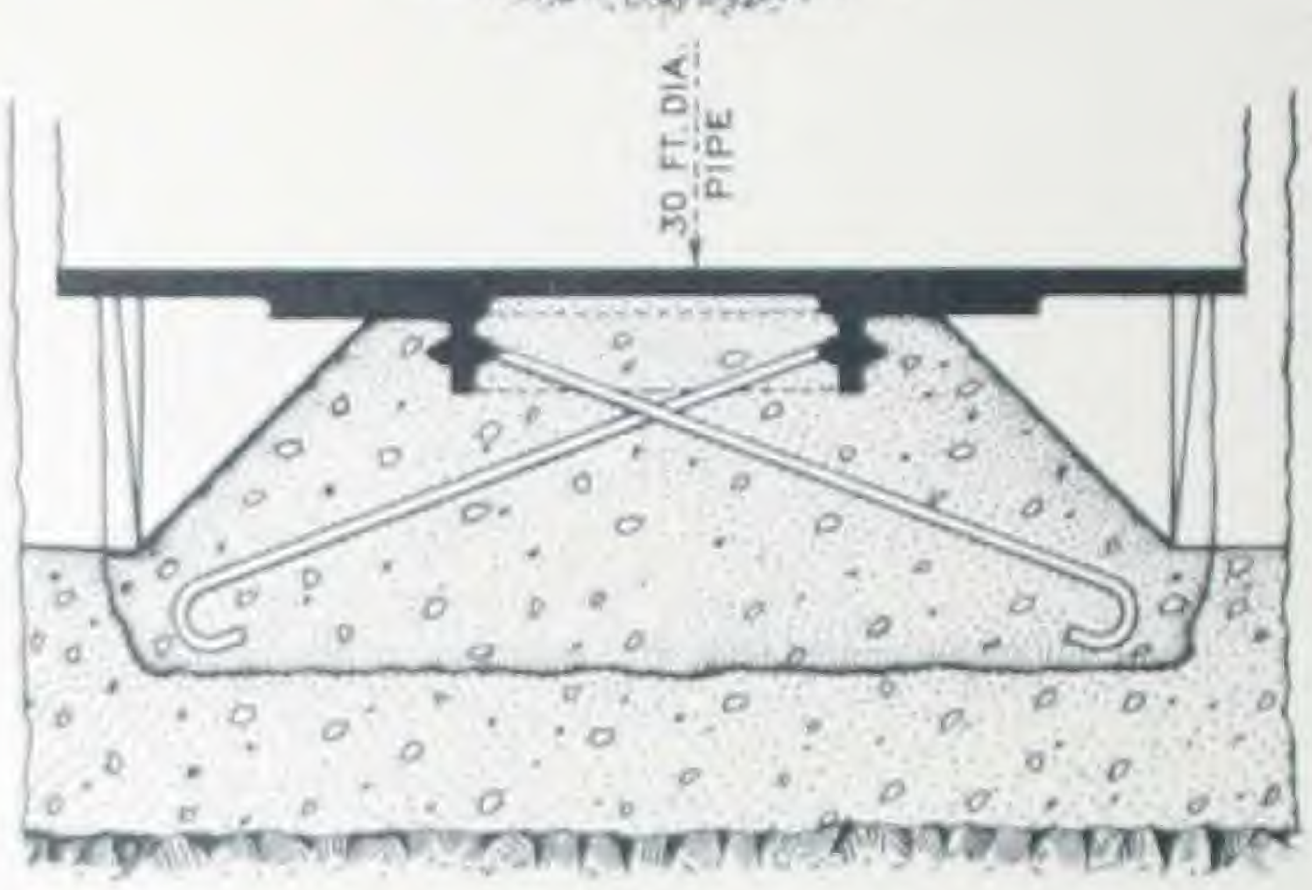
Cross-section sketch showing the location of the cable-way, landing ledges, and construction tunnels through which the pipes will be transported into the main tunnels.

One piece of 30-foot diameter pipe approximately 12 feet long will be made from three steel plates, each about 32 feet long and 12 feet wide, the largest that can be rolled with existing steel-mill equipment. The thickest plates will weigh about 23 tons each, and two of these are all that can be shipped in one car from the steel mill to the fabricating plant. These plates, after being formed, will be joined by fusion-welding and in accordance with the rules of the A.S.M.E. Boiler Construction Code, Unfired Pressure Vessel Section for Class 1 Welding. In fabricating this pipe, over 400,000 linear feet of welding will be performed. Incidentally, the amount of X-ray film used to prove the soundness of the welds will exceed the total of all that used to date, in this country, for industrial purposes.

Two pieces of 30-foot diameter pipe, each about 12 feet long, when welded together will comprise an erection-section which, with support brackets and stiffening rings to hold the pipe in shape, will weigh, when made of plate of the maximum thickness required, about 150 tons.

Sections will be transported from the fabricating plant to the rim of the canyon on special trucks or carriages comparable in load-carrying capacity with those used for mobile coast-defense guns. A cableway extending across the canyon will provide means by which the 150-ton sections may be lowered about 600 feet to landing ledges cut into the canyon walls on both sides of the river, at the construction entrances to the four tunnels. This cableway will have a clear span of 1260 feet, and its capacity will be more than double that of any other used to date for any similar purpose.

Handling-equipment of special design will be used to transport the gigantic pipe sections from the landing ledges into the tunnels and to their final positions, the first sections erected in each tunnel being set vertically under the inlet towers.



Typical section through the 37-foot and 50-foot diameter tunnels, showing the location of the 30-foot diameter pipe, proposed arrangement of the anchors, and the passageway around or through the anchor walls.

This yawning cavern is the mouth of one of the 50-foot diameter diversion tunnels.

Interior of one of the 50-foot diameter diversion tunnels.

In addition to the problems incident to the fabrication, handling, and installation of sections of pipe of a size comparable with that of the average three-story dwelling, the climate itself introduces a problem which is of considerable importance. During the summer, the temperature in this region ranges from 95 degrees fahrenheit at night to as high as 120 degrees during the day. Consequently, the temperatures of the pipes will be considerably higher during most of the erection period than they will be when water is turned into them. It is, of course, out of the question to provide expansion joints to absorb the movement due to expansion and contraction either during the erection period or afterwards. Accordingly, the pipes will be secured to massive steel-and-concrete anchors, placed about 400 feet apart; and during erection, one circumferential pipe-joint midway between each pair of anchors will be left open temporarily, and the final connections made after the pipe has been cooled to the approximate temperature of the water. It may be possible to make these connections during the winter, when the temperature drops to as low as 20 degrees outside the tunnels, and when the air in the tunnels may be sufficiently cold for the purpose, but if this is not feasible, artificial cooling will be employed.

Work on the Hoover Dam project is so scheduled that generation of electric power by some of the turbines will be considerably in advance of the final completion of the dam. In accordance with this schedule, all pipe work must be completed before the end of 1937.

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